Summary Statistics for TA_MH02_130827: Micro-CT Data Acquired at LLNL, Specimen 2 of 3

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Executive Summary

TA_MH02_130827				
Measured Density: 1.12 **g/cm^3**		**X-ray tube voltages (source filter materials)**		
Parameter		μ_L 100 kV(Al), Al-BHC	μ_L 100 kV(Al), H_2O-BHC	μ_H 160 kV (AlCu)
LAC	*Mean Measured LAC (LMHU)*[1]	1650	1591	1074
	Standard Deviation/Mean	8%	6%	7%
	Entropy	6.36	6.00	5.76
$^{L}Z_{eff}$	*From the mean measured LACs*	8.26		
$^{LW}Z_{eff}$	*From the mean measured LACs*	7.37		
μ_L/μ_H	*Using Al-BHC*	1.54		
μ_L/μ_H	*Using H_2O-BHC*	1.48		
QA	*From Cu strip and References*	Pass		

Table 1. *First-order statistics of the x-ray linear attenuation coefficient (LAC) in TA_MH02_130827, the estimated value of the effective atomic number, Z_{eff}, [1] and μ_L/μ_H. Z_{eff} is calculated from the ratio of μ_L/μ_H. Beam hardening compensation has been applied to μ_L using both aluminum ($^{L}Z_{eff}$) and water ($^{LW}Z_{eff}$) beam hardening parameters.*

Using x-ray micro computed tomography (MicroCT), we have characterized the linear attenuation coefficients (LAC), μ, of a sample of a dry powder material, tartaric acid (TA). The specimen was prepared at Lawrence Livermore National Laboratory (LLNL), loaded into a 60mL low density polyethylene (LDPE) bottle. After completed packing, the specimen was scanned following the protocol for MicroCT measurements under Test Plan 79 [2].

This particular specimen, TA_MH02_130827, recorded the bulk packing density (mass of sample divided by volume of sample) shown above. Two additional preparations were made and analyzed [3-4]. We used the computer program IMGREC to reconstruct the CT images. The values of the key parameters used in the x-ray data capture and image reconstruction are given in this report. Additional experimental details may be found in the SOP [5] and a separate document [6]. To characterize the statistical distribution of LAC values in each CT image, we first isolated an ~80% region or segment of volume elements ("voxels") lying completely within the sample, away from the walls of the container. We then calculated the mean value, standard deviation and entropy for (a) the high and low energy image segments and for (b) their digital gradient images[2]. The statistics of the initial image of LAC values are called "first order statistics;" those of the gradient image, "second order statistics." See Seetho [7] for details of the analysis used to obtain the numbers reported in this document.

[1] LMHU: "LLNL modified Hounsfield units with respect to water." To obtain the LAC in LMHU for some material at any energy, we multiply by 1000 and divide by the LAC of water at an x-ray energy of 160 kV with aluminum and copper filters.

[2] A digital gradient image of a given image was obtained by taking the absolute value of the difference between the initial image and that same image offset by one voxel horizontally, parallel to the rows of the x-ray detector array.

Summary of TA_MH02_130827 X-ray Statistics

Report Date: December 11, 2013

Report Prepared by: Isaac Seetho — LLNL
Typed or Printed Name — *Organization*

QA: Isaac Seetho — LLNL
Typed or Printed Name — *Organization*

Material ID(s): TA_MH02_130827

Source			Collimator	Beam Hardening	Sample Preparation	X-ray Measurement	Linear Attenuation Coefficient (LAC)		
Bias (kV)	Filters: Material	Filters: Thickness	Number of slits	Parameter Source	Date	Date	Statistic	1st order	2nd order
100	Al	1.943 mm	2	H_2O	8/9/2013	8/27/2013	**Mean**	1591	76
							Std. Dev.	98	59
							Entropy	6.00	5.31
100	Al	1.943 mm	2	Al	8/9/2013	8/27/2013	**Mean**	1650	89
							Std. Dev.	140	69
							Entropy	6.36	5.47
160	Al Cu	1.943 mm 1.905 mm	2	None	8/9/2013	8/27/2013	**Mean**	1074	65
							Std. Dev.	77	50
							Entropy	5.76	5.15
$^{L}Z_{eff}$	**Based on measured LAC (Al-BHC)**							8.26	
$^{LW}Z_{eff}$	**Based on measured LAC (H_2O-BHC)**							7.37	
μ_L/μ_H	**Based on measured LAC (Al-BHC)**							1.54	
μ_L/μ_H	**Based on measured LAC (H_2O-BHC)**							1.48	

Table 2. *Key statistics [8] for x-ray measurements of Linear Attenuation Coefficient (LAC). $^{L}Z_{eff}$ is determined from 100 kV (Al) to 160 kV (AlCu) LAC (μ_L/μ_H) as given in reference [1]. The statistics here are from the 2-slit image data (not the 1-slit open image data).*

Comments: ______

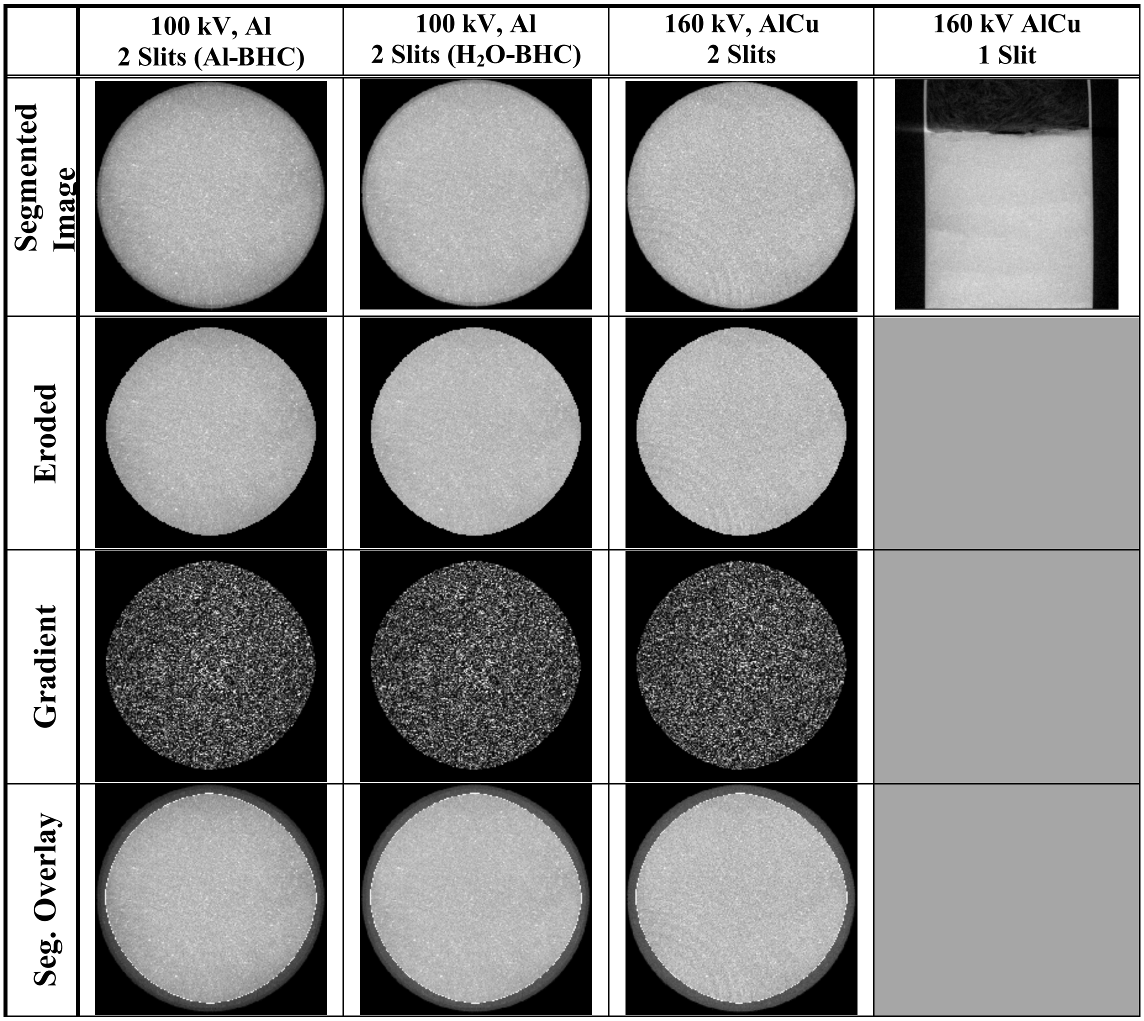

Figure 1. *X-ray slice images with 150µm × 150 µm × 150 µm voxels.* *Raw data (top row), segmented images (second row), eroded images (third row) used to calculate first order statistics. Fourth row, difference or gradient image used for second-order statistics. Images not to scale and use different gray scales to obtain maximum contrast. Single slit images (top right) are used for a qualitative visual assessment of homogeneity.*

Comments/Observations on Appearance of Sample (texture, color, other):

The material has a generally uniform texture. There are visible striations in the vertical full bottle image suggesting nonuniform density values vertically.

SUPPLEMENTAL ANALYSIS

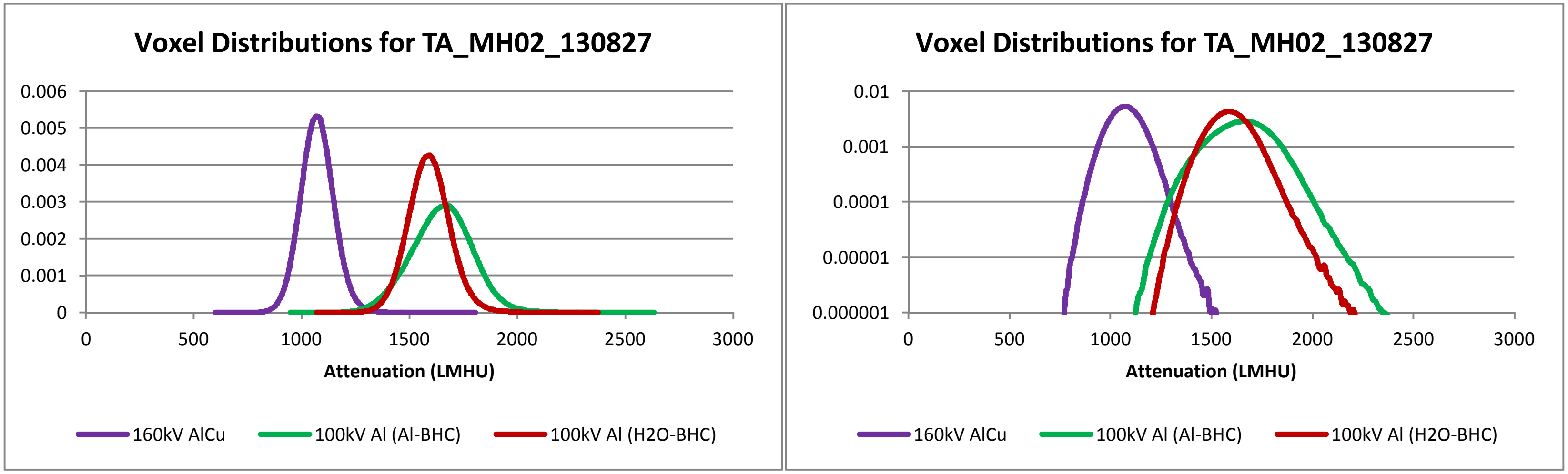

Figure 2. *KDE histograms of values of the linear attenuation coefficient (LAC) for TA_MH02_130827 for two x-ray source settings (linear plots – left; semi-log plots – right).*

Comments/Observations on Histograms: These histograms are made with a Gaussian Kernel Density Estimator (KDE) [8, 9] using 150-µm voxel upper-slit CT images.

Reference Specimens

	Parameter	*graphite*	*ethanol*	*Delrin**	*water*	*Teflon***	*aluminum****
100kV, Al (Al-BHC)	Mean (LMHU)	1732	1032	1802	1404	3037	7005
	Std Dev LMHU)	81	57	82	55	95	139
100kV, Al (H2O-BHC)	Mean (LMHU)	1845	1118	1932	1500	3165	6723
	Std Dev LMHU)	77	58	75	54	69	228
160kV, AlCu	Mean (LMHU)	1395	806	1339	1000	1922	2955
	Std Dev LMHU)	62	48	57	48	60	74

Table 3. *Linear attenuation coefficients of six reference materials as measured simultaneously with TA_MH02_130827***.**

** Acetron® GP copolymer. **Enflo Corp. PTFE. ***T6061 alloy.*

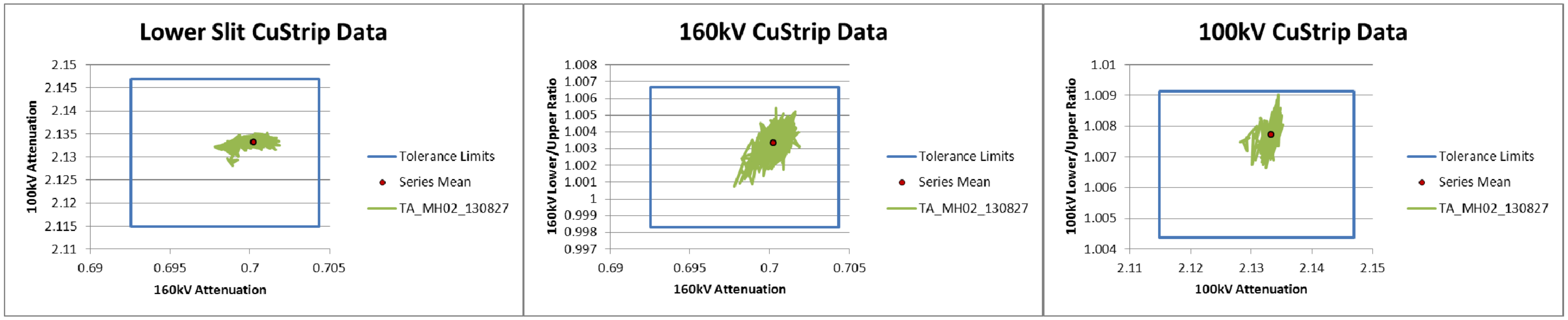

Figure 3. *Copper strip data are within the defined tolerance limits. These tolerance limits were defined using a set of scans spanning from April through May 2013.*

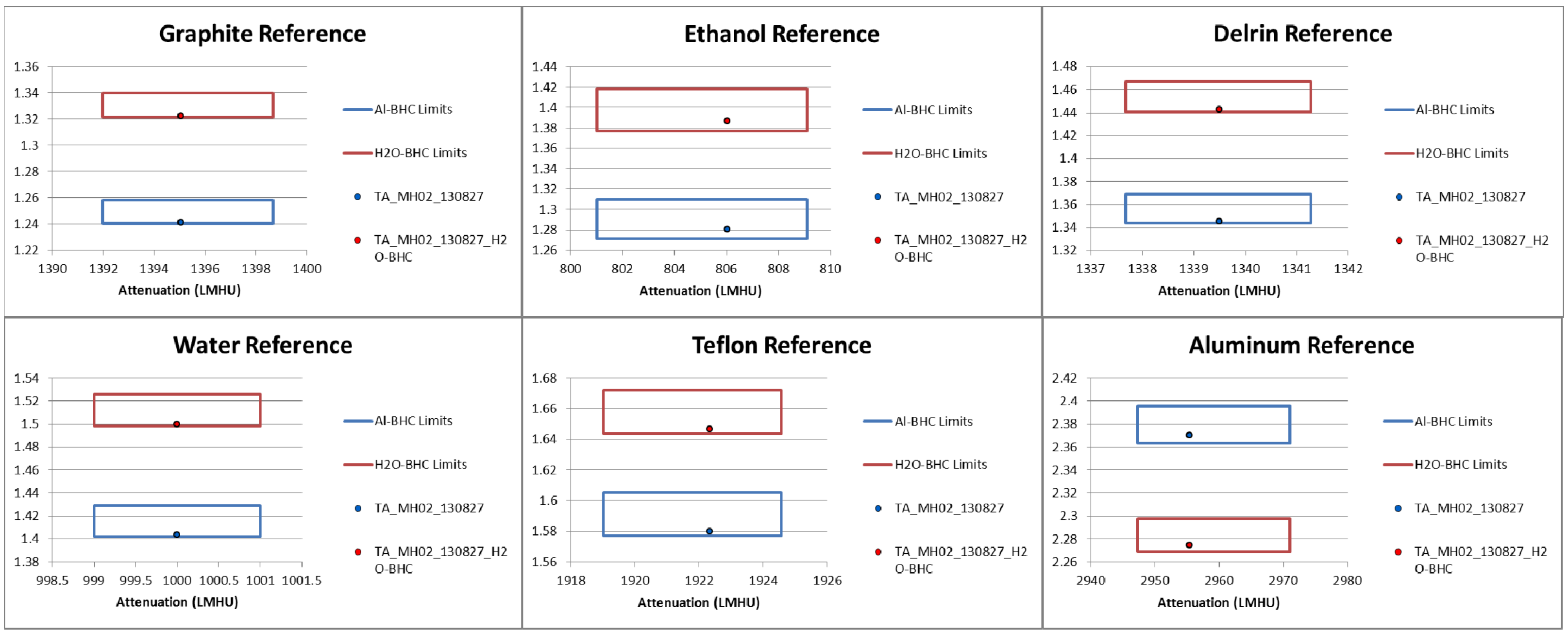

Figure 4. *Reference materials are within the defined tolerance limits. These tolerance limits were defined using a set of scans spanning from April through May 2013.*

Micro-CT System Configuration

1. Scan Location Site: LLNL HEAF
2. Source: Yxlon D09 450 kV Tube; Mfr. Catalog Number: 9421-172-33503; S/N 21-5204
3. Detector: Thales Flashscan 33 with Lanex Fine Gadolinium Oxysulfate Scintillator Screen; s/n 91106194
4. Rotation control system. Controller: Newport Model ESP7000 SN: 1250
5. Carousel: LLNL 2-tray, 6" Dia.
6. Data capture computer: Dell DHM/J4271

Micro-CT Scan Parameters

1. Scan Geometry:[1] SOD (mm): 1131.0 ODD (mm): 298.7

   Number of positions: 400 Angular Range: 200° Angular Increment: 0.5°
2. Number of Frames averaged per Image: 4
3. Integration time per frame: See p 7.

[1] Distances are those recorded in the .sct file for this experiment and are the values used in image reconstruction.

File Storage Locations for X-ray Data

Specimen

Root Data Path:

\Working\TP79_IMXXXXXX_Microstructure_Studies_V1\LLNL\None\HEAFCAT\None\TA_MH02_130827\Test_Data\{sub directory}\

Specimen ID	Date	Radiographer	Slits	kV	mA	Al Filter (mm)	Cu Filter (mm)	Integration *dpix* Setting [time/frame (s)]	{sub directory}	File Name
TA_MH02_ 130827	130827	Morales	2	100	1.1	1.943	0	8 [2.8s]	TA_MH02_130827_100Al	TA_MH02_100Al_*nn*.sdt[1]
	130827	Morales	2	160	4.35	1.943	1.905	8 [2.8s]	TA_MH02_130827_160AlCu	TA_MH02_160AlCu_*nn*.sdt
	130827	Morales	1	160	4.35	1.943	1.905	8 [2.8s]	TA_MH02_130827_ 160AlCu1slit	TA_MH02_160AlCu1slit_ *nn*.sdt

Dark current, mid-range, bright field and I_o

Root Data Path:

\Working\TP79_IMXXXXXX_Microstructure_Studies_V1\LLNL\None\HEAFCAT\None\TA_MH02_130827\Test_Data\{sub directory}\

Slits	kV	Filter	{sub directory}	Dark Image File Name	Mid-Brightness Image File Name	Max Brightness Image File Name	*Io* Image File Name
2	100	Al	TA_MH02_130827_100Al	TA_MH02_100AldrkR.sdt	TA_MH02_100AlmidR.sdt	TA_MH02_100AllitR.sdt	TA_MH02_100Albak.sdt
2	160	AlCu	TA_MH02_130827_160AlCu	TA_MH02_ 160AlCudrkR.sdt	TA_MH02_160AlCumidR.sdt	TA_MH02_160AlCulitR.sdt	TA_MH02_160AlCubak.sdt
1	160	AlCu	TA_MH02_130827_ 160AlCu1slit	TA_MH02_ 160AlCu1slitdrkR.sdt	TA_MH02_ 160AlCu1slitmidR.sdt	TA_MH02_ 160AlCu1slitlitR.sdt	TA_MH02_ 160AlCu1slitbak.sdt

[1] *nn* - is the CT angular index number (0 through 399) for each individual data file

Reconstruction

Reconstructed by: Kenneth E. Morales

Date: 8/27/2013

Location: LLNL

Computer: Dell Precision 690

Reconstruction Software

Software: IMGREC

Version: 2.8.1.1c11

Beam hardening compensation: Only for 100 kV Al filtered data using Al and H_2O reference materials for compensation.

Script Files

LLNL_script_TA_MH02_100Al.txt
LLNL_script_TA_MH02_160AlCu.txt
LLNL_script_TA_MH02_160AlCu1slit_tw_WDB.txt
LLNL_script_H2OBHC_TA_MH02_100Al.txt

Reconstructed Specimen Files

Root Data Path:
\Working\TP79_IMXXXXXX_Microstructure_Studies_V1\LLNL\None\HEAFCAT\None\TA_MH02_130827\Reconstruction\Recon_130827\{sub directory}\

Slits	kV	Filter	{sub directory}	Reconstruction file name
2	100	Al	TA_MH02_130827_100Al	`recobj_`*nn*[1]`.sdt`
2	100	Al	H2O_Recon\TA_MH02_130827_100Al	`recobj_`*nn*`.sdt`
2	160	AlCu	TA_MH02_130827_160AlCu	`recobj_`*nn*`.sdt`
1	160	AlCu	TA_MH02_130827_160AlCu1slit	`recry_`*nn*`.sdt ,ry_`*nn*`.sdt`

Observations:____

[1] *nn* - is the index number for each reconstruction file, modified by an offset corresponding to the frame subsection extracted and analyzed.

Analysis

Analysis by: Isaac Seetho

Date: 8/28/2013

Location: LLNL

Computer: Dell Precision T7500

Analysis Software

Software: MATLAB

Version: R2010b

GUI Function/Script Files

micro_ct_gui_1_3.m[1]

custrip_gui_split.m

Reference & Specimen Analysis Files

\Working\TP79_IMXXXXXX_Microstructure_Studies_V1\LLNL\None\HEAFCAT\None\TA_MH02_130827\Analyses\TA_MH02_130827_analysis_IMS_130828\

Analysis File	`TA_MH02_130827_characterization.xlsx`

\Working\TP79_IMXXXXXX_Microstructure_Studies_V1\LLNL\None\HEAFCAT\None\TA_MH02_130827\Analyses\TA_MH02_130827_H2O-BHC_analysis_IMS_130828\

Analysis File	`TA_MH02_130827_H2O-BHC_characterization_Corrected.xlsx`

Copper Strip Analysis Files

Root Data Path:

\Working\TP79_IMXXXXXX_Microstructure_Studies_V1\LLNL\None\HEAFCAT\None\TA_MH02_130827\Analyses\TA_MH02_130827_custrip_IMS_130828\

Aggregate Statistics	`Stats_TA_MH02_130827_W80xH7.xls`
Mean Value Time Series	`Custrip_TA_MH02_130827_W80xH7.xls`

[1] Analysis using the MicroCT GUI is done according to the steps outlined in reference [7].

REFERENCES

1. Jeffrey S. Kallman, Daniel J. Schneberk, Harry E. Martz, Jr., *Two-energy Ratio Method to Determine Zeff from Reference Materials: A Comparison of an Explosive and a Simulant*, Version 3, Lawrence Livermore National Laboratory, LLNL-TR-491153, June 24, 2011.
2. Stephen Azevedo, Jeffrey S. Kallman, Harry E. Martz, Jr., *TP79 – Microstructure Studies Using MicroCT and EDS for DHS R&D*, Lawrence Livermore National Laboratory.
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5. "Standard Operating Procedure — Industrial Computed Tomography System Data Collection of Home-Made Explosives," U.S. Department of Homeland Security Science and Technology Directorate, DHS/STD/TSL-xx-xx, July 9, 2009.
6. Jerel A. Smith, Daniel J. Schneberk, Jeffrey S. Kallman, Harry E. Martz, Jr., David Hoey, *Documentation of the LLNL and Tyndall Micro-Computed-Tomography Systems*, Version 091216, Lawrence Livermore National Laboratory, LLNL-TR-421377, December 17, 2009.
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9. B. W. Silverman, *Density Estimation*, Chapman and Hall, 1986.